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UTILIZATION OF FLUE GASES HEAT FROM BOILERS IN CONTACT-TYPE WASTE HEAT BOILERS

Regularities of heat recovery intensity of flue gases change from the boilers at the expense of «dry» and condensation heat exchange in contact type waste heat boilers are analyzed. Convenient formulas for calculation of thermal capacity of the recovery have been obtained. Gas saving at the expense of recovery in certain steam and hot water boilers has been determined. In accordance with this economy reduction of harmful emission in the atmosphere is evaluated.

Key words: *flue gases, contact waste heat boiler, dew point temperature, steam boiler, hot – water boiler.*

Problem set-up

As a result of problems, dealing with the supply of natural gas and growth of its cost, nowadays, the strategic task is economy of this kind of fuel. One of the priority means of natural gas saving is the application of low temperature dump energy of combustion products in fuel-fired installations, especially in steam and hot water boilers.

Energy levels of heat losses of industrial and heating boilers, according to expert estimations are almost 45 % of the total volume of fuel-energy resources [1]. In regional and district centers of Ukraine numerous industrial and hot-water boiler houses, equipped with small capacity natural gas-fired boilers, still operate. Such boilers, as a rule, do not have the developed back-end surfaces of heating and are characterized by rather high temperature of flue gases (t_{fg}>130 °C).

Combustion products of natural gas contain high concentration of water vapour, certain portion of fuel heat burning is spent for its formation. By means of compact-type waste heat boiler (contact waste heat boilers), the temperature of flue gases from the boilers can be decreased to the temperature, that is less than the dew point temperature t_R, i. e., $t_{whb} < t_R$. This enables to use both physical (dry) and condensation (humid) components of flue gases heat.

Recovered heat of flue gases, as a rule, is used outside the boiler in a certain element of thermal circuit of boiler house, for instance, for heating of unboiled or chemically purified water. Due to the heat, recovered in contact waste heat boiler, heat losses for own need are reduced. Accordingly, thermal capacity of the boiler also decreases, that stipulates the reduction of working fuel consumption in the boiler. As a result, certain economy of the fuel is achieved. The reduction of fuel consumption stipulates certain reduction of harmful emissions in the atmosphere and lowering of electric energy consumption for the drive of forced – draft installations.

Proceeding from the above mentioned: the following tasks were put forward: determine general regularities of recovery components of flue gases heat recovery; evaluate the efficiency of recovered heat usage in boilers of different types.

Main results

Operation of the boiler in nominal modes is characterized by almost invariable values of the coefficients of air excess in the furnace and in flue gases, temperatures of flue gases and cold (in premise) air and thermal losses as a result of chemical incompleteness of fuel combustion q_3 and in the environment q_5. The greatest thermal loss with flue gases q_2, as it is known [2 – 5] depends on the temperatures of flue gases and cold air, coefficient of air excess in flue gases. Instead of bulky calculations of specific volumes of fuel combustion products and their enthalpies, needed for q_2 determination according to normative method, [4] simpler formulas are used [2, 3]. Proceeding form the data, regarding the composition and properties of natural gases from different gas fields with the heat of combustion on dry mass 31 – 37,9 MJ/m^3 [4, 6], generalized formula for q_2 %, calculation is obtained, this formula agrees with the accuracy ±0,14% with q_2 values, calculated by the normative method [4]:

$$q_2=[(0,0343\cdot\alpha_{fg}+0,00782)t_{fg}-exp(0,4324\cdot\alpha_{fg}-0,3746)]\theta^{0,33}, \quad (1)$$

where α_{fg}– coefficient of the air excess in flue gases; $\theta=[293/(t_{ca}+375)]$; t_{ca} – temperature of the cold air.

For simplification of the calculations the dependences $q_2=f(\alpha_{fg}, t_{fg})$ for θ=1 are given in Fig. 1.

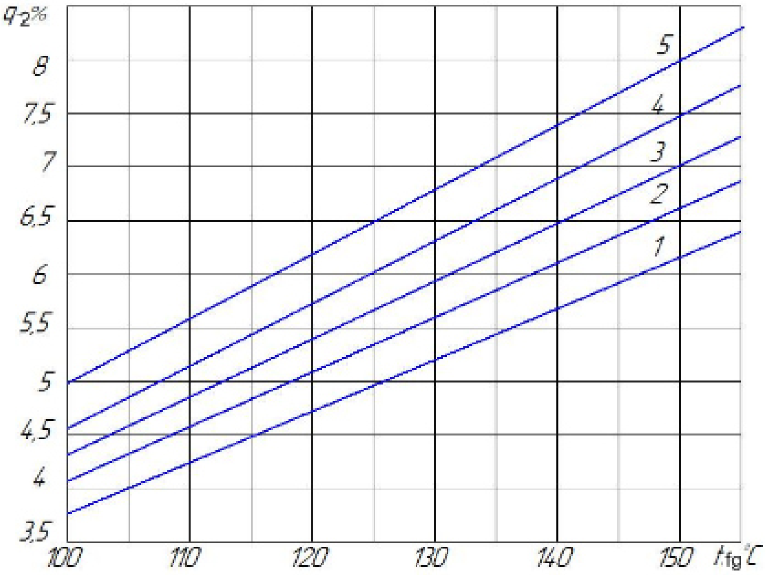

Fig. 1. Values of q_2: 1- α_{fg}=1,2; 2-1,3; 3-1,4; 4-1,5; 5-1,6

For the set thermal capacity of the boiler Q_b the consumption of the working fuel equals, m^3/sec

$$B_w= Q_b/(Q^d_l\cdot\eta_b), \quad (2)$$

where Q^d_l – heat of combustion of natural gas on dry mass, MJ/m^3; η_b – efficiency of the boiler.

Thermal capacity, recovered in contact waste – heat boiler due to «dry» heat exchange, is calculated by the formula, MW [7].

$$Q_d = Q_{fuel}(1- \eta_b)\psi_d, \quad (3)$$

where $Q_{fuel}= C_w\cdot Q^d_l$ – thermal capacity of burnt fuel; $\psi_d=(t_{tg}- t_{whb})/ t_{fg}$ – coefficient of heat recovery due to “dry” heat exchange; t_{whb} – temperature of flue gases at the outlet of contact waste – heat boiler.

Regularities of recovery coefficient change ψ_d are shown in Fig. 2.

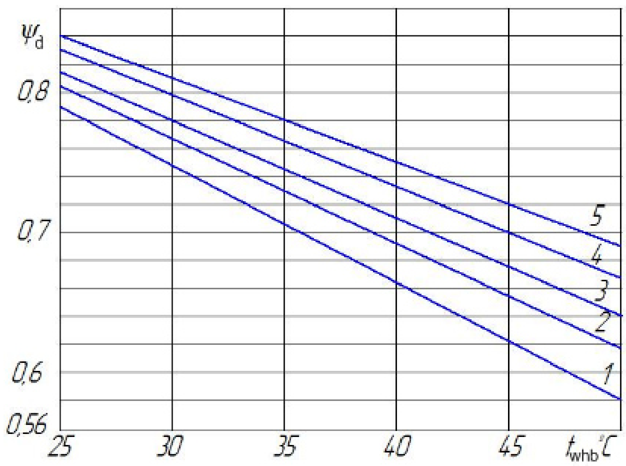

Fig. 2. Values of heat recovery coefficient due to «dry» heat exchange: 1-t_{fg}=120 °C; 2-130; 3-140; 4-150; 5-160

It is seen from Fig. 2 that the intensity of «dry» heat exchange decreases linearly with the decrease of flue gases temperature and temperature of gases behind contact waste heat boiler (with the decrease of gas cooling degree) in contact waste heat boiler.

Dependences, given in Fig. 2, are approximated by the formula:

$$\Psi_d=1-(0,6143-5\cdot10^{-5}\cdot t_{fg})\cdot t_{whb}, \qquad (4)$$

Fig. 3 contains calculated values of specific utilization capacity q_d at the expense of «dry» heat exchange in contact waste boiler for Q_{fuel} =1 MW.

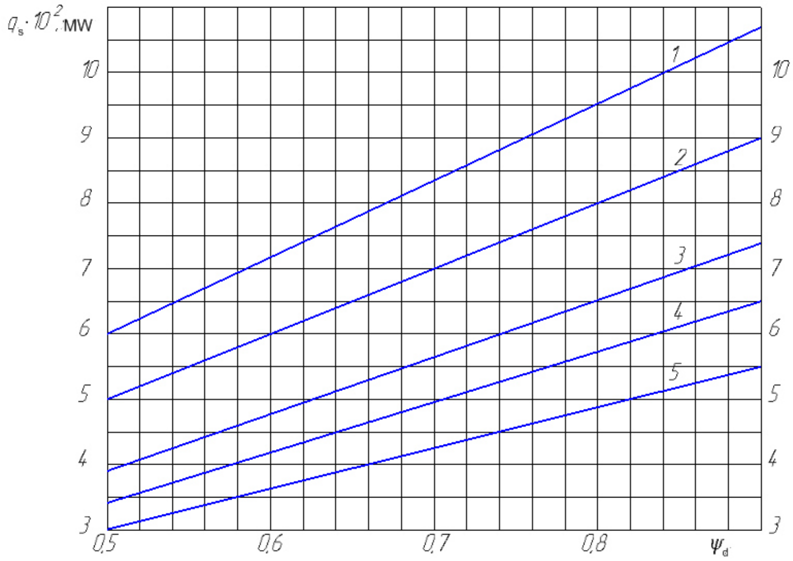

Fig. 3. Dependences $q_d= f\,(\psi_d,\ \eta_b)$ for «dry» heat exchange: 1- η_b=0,88; 2-0,9; 3-0,92;4-0,94; 5-0,96

Recovery capacity at the expense of «dry» heat exchange increases linearly with the increase of recovery coefficient and decrease of boiler efficiency

Thermal capacity, recovered in contact waste heat boiler at the expense of water vapour condensation from fuel combustion products is

$$Q_{cd}= B_w(Q^d_h- Q^d_l)\,\psi_{cd} = B_w\cdot Q^d_l(Q^d_h/ Q^d_l-1)\,\psi_{cd}= Q_{fuel}(Q^*-1)\,\psi_{cd}, \qquad (5)$$

where Q^d_h – is high heat value of working fuel, that exceeds low heat of combustion heat by the heat of water vapour compensation ; $\psi_{cd}=(\ t_R-\ t_{whb})/\ t_R$ – condensation coefficient of heat recovery; $Q^*= Q^d_h/ Q^d_l$.

Temperature of the dew point t_R may be defined by [10, 17] ^oC.

$$t_R=117,5\cdot\alpha_{fg}^{-0,155}-57,09, \quad (6)$$

Relation Q^* for gaseous fuels, according to [10, 11] is 1,111 – 1,1124. In contact waste heat boilers dew point temperature increases as a result of increase of water vapour fraction in flue gases. Besides, the increase of moisture content allows to obtain the additional effect in the form of reduction of oxides of nitrogen emissions in the atmosphere [10, 17].

Calculated values of heat utilization coefficients at the expense of water vapour condensation are given in Fig. 4.

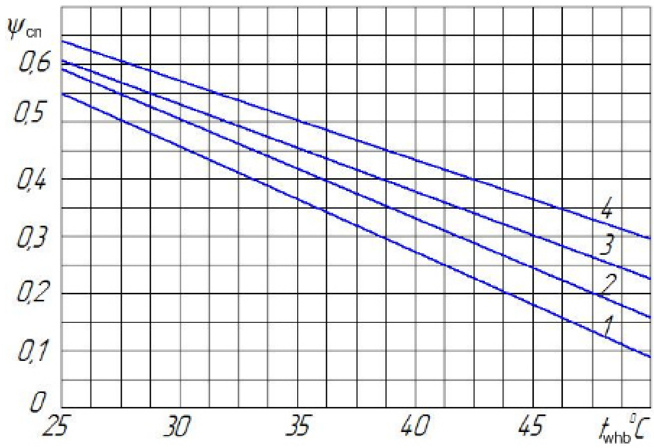

Fig. 4. Regularities of the coefficients of condensation component of heat recovery change in flue gases: 1- t_R=55°C; 2-60; 3-65; 4-70

It is seen form Fig. 4, that the character of ψ_{cd} coefficients change is similar to the character of ψ_d, coefficients, given in Fig. 2. Main impact on the intensity of heat exchange at the expense of water vapour condensation, as in Fig. 2, exercises the temperature of gases behind the contact waste heat boiler, with its increase the value of ψ_{cd} decreases, and with the increase of dew point temperature the intensity of condensation component of heat exchange increase.

Dependences in Fig. 4 are approximated by relation

$$\Psi_{cd}=1-(0,02656-1,554\cdot10^{-4}\cdot t_R)\, t_{whb} \quad (7)$$

It is clear that the formula (7) by its structure corresponds to the formula (4) but for the same interval of gases temperature change behind the contact waste heat boiler, the values of coefficients ψ_d exceed the value of ψ_{cd}.

Fig. 5 contains calculated values of specific power of heat exchange condensing component in flue gases q_{cd} for Q_{fuel} = 1 MW.

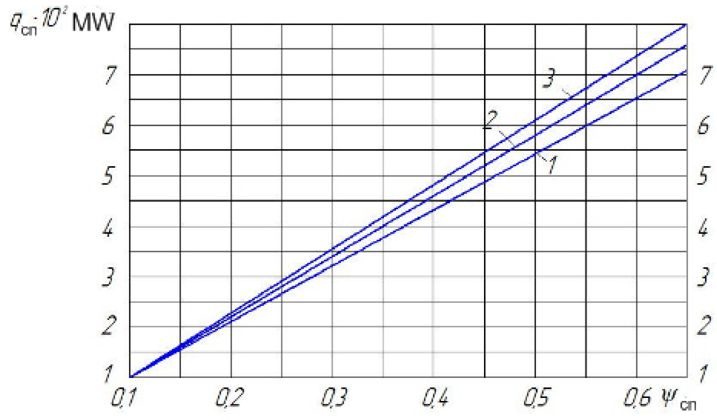

Fig. 5. Dependences of specific power change due to condensation heat exchange in flue gases:
1- Q^*=1,111; 2-1,118; 3-1,124

Recovery capacity at the expense of condensation heat exchange in flue gases increases as the utilization coefficients ψ_{cd} and Q^* increase. More important differentiation of q_{cd} values is observed at ψ_{cd}> 0,25. By absolute magnitudes the value of q_{cd} is less than values of q_d.

Total value of power, recovered in contact waste heat boiler equals

$$Q_{whb}= B_w\cdot Q^d_l(q_d+ q_{cd})= Q_{fuel}(q_d+ q_{cd}) \quad (8)$$

Recovery power, used in certain heat exchange device of thermal circuit of boiler house, will be

$$Q_{rec}= Q_{whb}\cdot\eta_{he} \quad (9)$$

where η_{he} efficiency of the given heat exchanger.

In case of usage of thermal power Q_{rec}, thermal power of the boiler must decrease by this value and it will equal

$$Q'_b = Q_b - Q_{rec} \quad (10)$$

Neglecting minor change of heat loss in the environment of the boiler, the economy of operating fuel will be:

$$\Delta B_w= Q_{rec}/(Q^d_l \cdot\eta_b) \quad (11)$$

As it was mentioned above, decrease of energy consumption in the boiler stipulates the decrease of electric power on the drives of draft system (ventilator and induced – draft fan) and also the decrease of harmful emissions in the atmosphere.

Hence, simple and convenient for engineering practice formulas for calculation of complete utilization power and fuel saving in case of application of flue gases heat recovery in contact waste heat boilers are obtained. Proceeding from the results obtained operation indices of certain steam and hot-water boilers with flue gases heat recovery are calculated.

In the calculations the temperature of dew point and temperature of gases behind the contact waste heat boiler is 56 ^{o}C and 40 ^{o}C, correspondingly. Coefficient of air excess in flue gases in all the boilers is chosen to be 1.28. Fuel – is natural gas, its heat of combustion is 33,4 MJ/m ^{3}, and theoretical volumes of air and combustion products are 9,52 and 10,62 m^3/m^3, correspondingly. Relation of high heat value to low heat value is chosen to be 1,112. For determination of flue gases temperature and heat losses q_3 and q_5 literature sources [5, 6, 12] and parameter tables of the boilers that function at industrial and heating boiler houses of Vinnytsia were used. Pressure and efficiency of draft installations is: 3,2 kPA and 0,7 for the ventilator and 2,5; 0,65 for induced – draft fan, efficiency of heat exchanger equals 0,98. Annual term of operation is 7800 hours. Calculations of thermal circuits of boilers are given in [13]. Emissions of harmful substances in the atmosphere were defined in accordance with Maximum Allowable Concentration (MAC) 34.02.305.-2002 ″Emissions of polluting substances in the atmosphere from energy installations”. Type of boilers and their operation indices are given in the table.

Operation indices of boilers with flue gases heat recovery

Indices	Type of boiler			
	ДКВР-20-13-250	БГ-35	КОЛВІ 10000	ПТВМ-90
Thermal capacity of the boiler, MW	14.02	26.25	10	34.86
Temperature of flue gases, ^{o}C	150	130	145	155
Heat losses with flue gases, %	7.02	5.92	6.71	7.27
Heat losses in the environment, %	1.3	1.1	1.55	0.95
Heat losses due to incomplete combustion, %	0.03	0.022	0.025	0.02
Efficiency	0.9165	0.9295	0.9171	0.9176
Working fuel consumption, m^3/s	0.4580	0.8455	0.3264	1.1374
Thermal capacity of the burnt fuel, MW	15.297	28.2397	10.9017	37.9891
Recovery ratio for «dry» heat exchange	0.7333	0.692	0.724	0.7419
Specific capacity of «dry» heat exchange, MW	0.0612	0.04878	0.0600	0.06113
Recovery ratio of condensation heat exchange	0.3103	0.3103	0.3103	0.3103
Specific capacity of condensation heat exchange, MW	0.0372	0.0372	0.0372	0.0372
Recoverable thermal output of waste heat boiler, MW	1.505	2.428	1.0596	3.735
Economy of working fuel:				
m^3/s	0.04818	0.0782	0.0339	0.1194
%	10.5	9.25	10.386	13.01
Annual economy of working fuel, thous·m^3	1352.89	2195.85	951.91	3352.75
Reduction of drives powers of draft systems, kW	6.28	9.72	4.48	12.25
Annual economy of electric energy, MW·hr	48.984	75.816	34.944	95.55
Annual reduction of harmful emissions in the atmosphere, tons (CO_2)				
	8.935	14.720	6.291	21.727
	264.14	414.53	185.99	664.54
	1805.74	2923.34	1273.23	4432.89

The results, given above, show the expediency of recovery application of flue gases from steam and hot water boilers, operating on gaseous fuel. As a result of the recovery the economy of working fuel, reduction of energy consumption on proper needs of boiler installation and decrease of polluting emissions in the atmosphere could be achieved. Recovery efficiency can be increased as a result of increasing dew point temperature. If not one but two or more boilers operate in boiler house, the charges for fuel, electric energy and harmful emissions could be considerably reduced. Depending on the capacity two or more boilers can operate on one recovery installation, this considerably reduces the term of its recoupment [9, 14, 15, 16].

The results, obtained may serve as necessary precondition for the selection of the type of condensing utilizers and express – evaluation of the recovery efficiency of flue gases from boilers.

Conclusions

1. Convenient formulas for engineering practice, intended for determination of heat losses with flue gases in boilers, coefficients, characterizing the intensity of heat recovery at the expense of

«dry» and condensing heat exchange are obtained.

2. It is revealed that main factors of recovery intensity of flue gases are: temperature of flue gases, temperature of flue gases behind the economizer and dew point temperature.

3. It is established that in the process of recovery of flue gases heat from the boilers the economy of working fuel within the limits of 9,25 – 13% and reduction of electric energy losses for own needs as well as decreases of harmful emissions in the atmosphere could be achieved.

4. The results of the research can be used for the selection of contact waste heat boiler type and evaluation of the efficiency of flue gases heat recovery.

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